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Large-Scale Shell Model Calculations for Odd-Odd Nuclei and Comparison to Experimental Studies of Fission Product Nuclei in the ^{132}Sn Region*

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ABSTRACT

Experimental spectroscopy data of fission products have been obtained using highly automated and rapid chemical separations followed by automated spectroscopy studies of isolated fission products. These data have established the presence of only a single level with spin-parity of 1^+ below 1500 keV of excitation in Z=51 $^{132}Sb_{81}$. This is in contrast to the results of our studies of ^{130}Sb and ^{134}I. For ^{134}I, the N=81 isotone with Z=53, we can characterize three 1^+ levels below 1200 keV. For $^{130}Sb_{79}$ that has a neutron pair less than ^{132}Sb, we can identify two 1^+ levels below 1100 keV. We can account for the additional levels using the LLNL shell-model code which is based on the Lanczos tridiagonalization algorithm using an uncoupled m-scheme basis and vector manipulations. The $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $1h_{11/2}$, and $3s_{1/2}$ orbitals are available to the valence protons and the $2d_{5/2}$, $2d_{3/2}$, $1h_{11/2}$, and $3s_{1/2}$ orbitals are available to the valence neutron holes. Analysis of the wavefunctions show the dominant role of three nucleon cluster configurations in producing the increased number of states at low energy. The absence of nucleon cluster configurations in the parent nucleus ^{130}Sn is used to explain the reduction of approximately a factor of 20 in the Gamow-Teller beta strength to the low lying 1^+ levels of ^{130}Sb.

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1. INTRODUCTION

The nuclei near the double shell closure nucleus ^{132}Sn can provide a good test of large scale shell model calculations. However, detailed experimental information had been lacking. Here we give the results of detailed spectroscopy studies based on nuclear chemistry techniques and compare them to large scale shell model calculations. Some results and comparisons have been given elsewhere.[1-7] Details of the experimental studies are given in ref. 1,2,6 and 7 while the calculations are described in detail in ref. 1,7 and 8 and are based on works given in refs. 9 through 15. Also, previous studies are reported in refs. 16 through 27.

2. EXPERIMENTAL AND CALCULATIONAL TECHNIQUES

2.1 Chemical Separations and Spectroscopy

Short-lived fission products were isolated using the LLNL AUTOBATCH system. This system, described in detail elsewhere[1,6], chemically separates fission products that were produced in a uranium sample loaded in a rabbit. The rabbit entered a reactor through a pneumatic tube and returned to a chemical-processing station under microprocessor control. The hydrides of Groups Va and VIa elements were produced through reaction of an acidified fission-product mixture with sodium borohydride solution. The hydride gases of unwanted homologues were then separated by passing them through a series of chemical traps. The first was a NaOH trap which removed H_2Se and H_2Te while a $CaSO_4$ trap eliminated GeH_4. The Sn hydride was decomposed on a filter made of glass wool soaked in a saturated solution of KOH in methonol. Any AsH_2 present passed through a glass wool filter and was discarded in the waste. Similar techniques were used to isolate tellurium.[5,6] The final trap that caught the fission product to be studied, was situated in between a pair of detectors.

Three types of gamma-ray spectra were taken: single-parameter, multiscaled single-parameter, and three-parameter coincidence. For the coincidence experiments, the gamma-ray events were acquired in an 8192 channel ADC and the time spectra in a 512 channel ADC. Coincidence data were stored using a buffer tape system. Two separate coincidence experiments were performed, both of which accumulated over 25 million events. In the first experiment, the lower-energy transitions (0 to 1200 keV) were measured while in the second a full energy range was used (0 to 4000). Details of the experimental set up and procedures are given elsewhere.[7]

2.2 Calculational techniques

In order to extend shell-model calculations to a larger dimension Hausman and Bloom have developed a computer oriented method for shell-model calculations[8,9] These calculations follow that first suggested by Sebe and Nachimkin[10] and by Whitehead[11,12] in which the traditional shell-model formalism of group theory, fractional parantage, and angular momentum theory were abandoned and replaced by a numerical technique such as the Lanczos algorithm.[13] In our calculations we have used this technique along with an effective interaction due to Petrovich, McManus and Madsen (PMM force).[14] This force, derived from the Kallo-Kolltveit force,[15] is written as:

$$V = [e^{-ar}/(r/a)]V_t P^{01} + V_s P^{10}$$

where the parameters take on the values of: V_t:(−)119.5 MeV; V_s:(−)73.5 MeV, and "a": 1 fm^{-1}. The quantities P^{01} and P^{10} are the triplet-even and singlet-even projection operators, respectively. The triplet-even and singlet-even exchange mixture is identical to that of the Kallio-Kolltveit force. We note that the PMM force has been used, without modification, in several widely-separated regions of the nuclide chart. Petrovich and McManus[16] have used the force to explain the

$^{90}Zr(p,p')$ reaction at 20 MeV. Hausman[8] applied this force to structure calculations in the ^{48}Ca region.

The single-particle energies (SPE) for the gddsh shell were determined from the spectrum of the one neutron-hole nucleus ^{131}Sn and the systematics of the N=81 and Z=50 nuclei.[16] The set of SPE used are (energy in MeV in Parenthesis): $1g_{7/2}$(−4.50); $2d_{5/2}$ (−3.83); $2d_{3/2}$ (−2.15); $3s_{1/2}$ (−2.57); and $1h_{11/2}$ (3.14). Using these values, the calculated levels of the single-valence proton nucleus, ^{133}Sb, were then compared with the ^{133}Sb experimental levels, with systematics of Z=51 odd-mass nuclei, and with the systematics of N=82 odd-mass nuclei. All these were found consistent with the available experimental data.[7] It should be noted that in contrast to other shell model calculations, the present technique explicitly accounted for <u>ALL</u> nucleons in the gddsh shell (except the $g_{7/2}$ neutrons) and therefore used the SPE values for both protons and neutrons. As noted earlier, similar techniques have been used by Sau and Heyde but with a different interaction.[3]

<u>3.EXPERIMENTAL RESULTS AND COMPARISON TO CALCULATIONS</u>

The level structure of odd-odd nuclei in the ^{132} Sn region can provide good tests for shell model calculations. One particular feature is the number of levels with spin-parity of 1^+. Based on the present and previous works, $_{51}Sb_{81}$ has only one 1^+ level below 1500 keV of excitation. However, for ^{134}I, the isotone of ^{132}Sb with Z=53 rather than Z=51, we have been able to identify and study in detail three 1^+ levels below 1200 keV of excitation. In this section we give the results of both our experimental studies that characterize the low-energy low-spin levels in the N=77, 79 and 81 isotopes of $_{51}$Sb and the N=81 isotone ^{134}I and compare the results to our shell model calculations.

<u>3.1 Levels of Z=51,N=81 ^{132}Sb</u>

In Fig. 1a we present the decay scheme for ^{132}Sn that we deduce from our data and previous studies. Our data shows that the third excited level observed in the beta decay of ^{132}Sn should be placed at 548 keV. Kerek et.al.[18] could only suggest that a level exists at either 529 or 549 keV. Our coincidence data confirms the placement of the 463- and 122-keV transitions as originating from a 548-keV level. All gamma rays with more than 2 units of intensity were measured to have a 40s half-life. When we take the measured Q value of 3080 ± 40 keV[19] and the 40s half-life of ^{132}Sn we obtain a log ft value[20] of 4.00 for the Gamow-Teller 0^+ to 1^+ beta transition. In Table 1, we give the calculated level wavefunctions for ^{132}Sb. The levels we observe are accounted for by our calculations. We note that the shell model calculations of Sau and Heyde using a different force[3] give similar results. However, the calculations using a delta force of Kerek et al.[18] give poorer agreement with our experimental results and calculations.

<u>3.2 Levels of Z=51, N=79 ^{130}Sb</u>

The levels of $^{130}Sb_{79}$ have been investigated independently by Kerek et al.[21] and by Nunnelly and Loveland.[22] However, our coincidence studies are the first to firmly establish the ^{130}Sb level scheme populated in the beta decay of ^{130}Sn. Nunnelly does not report the 341- and 726-keV positive parity levels. The gamma rays observed in the decay of $^{130}Sb^g$ are shown in Fig. 1b. The log ft values of 6.22 and 5.21 for the population of the 697- and 1042-keV levels are greater than one unit different than those given in the most recent edition of the Table of Isotopes.[16] As for the ^{130}Sb level structure, our calculated level structure is more consistent with the experimental results and the calculations of Sau and Heyde than with those of Kerek et al. Elsewhere,[2,7] we give a complete description of these calculations and experimental results. Also, we note that we can account for the 0^+ to 1^+ beta transition in the $^{130}Sn/^{130}Sb$ system being hindered by a factor of approximately 20 compared to the 0^+ to 1^+ beta transition on the $^{132}Sn/^{132}Sb$ system.[2] The hinderance can be shown to occur because the 1^+ states accessible to beta transitions are dominated by three hole cluster configurations and the parent g.s. lacks matching configurations.

3.3 Levels of Z=51, N=77 ^{128}Sb

Two investigations have been reported for the beta decay of ^{128}Sn to ^{128}Sb: one by Imanishi et al.[27] and the other by Nunnelly and Loveland[22]. A major discrepancy between them effects the number of low energy levels populated directly by beta decay (and hence candidates for 1^+ levels in ^{128}Sb). The discrepancy is in the placement of a 404- and 152-keV gamma-ray cascade. Imanishi et al. place the cascade as populating a 230.5-keV level which, because of gamma ray intensity imbalance, would require it to be populated in beta decay. This would create three low energy levels fed directly by beta decay of ^{128}Sn. Nunnelly and Loveland place the cascade as 152- to 440-keV gamma-ray cascade into the 78-keV level. This results in a 482.2-keV level which is not fed in beta decay. Our coincidence experiments confirm the assignment of Nunnelly and Loveland and establishes that only two levels are populated in the beta decay of ^{128}Sn. In addition, we find evidence for a 833- to 482-keV level transition, which suggests population of the 482-keV level from the 833-keV level.

3.4 Levels of Z=53, N=81 ^{134}I

We have identified several levels in ^{134}I in an earlier work[5] while in the present work we have accumulated data with greater statistics than before. In a separate set of experiments we have studied short-lived tellurium fission products. A by-product of these studies was high statistics three-parameter coincidence data for the decay of ^{134}Te to the levels of ^{134}I. These more recent experiments have given evidence for a 0^+ level at 856 keV. A 645.9-keV gamma ray was found to be in coincidence with the known 210-keV gamma ray. Its placement in the decay scheme is shown in Fig. 1c. The direct but low intensity population of the 0^+ level from the beta decay of ^{134}Te 0^+ g.s. with a log ft value of 7.7, is consistent with the expected mixing of he analog state into this level. As in lighter closed shell and near-closed shell nuclei, the Coulomb force provides analog state mixing that allows beta decay to occur in a normally totally forbidden 0^+ to 0^+ beta decay.[23]

Previously, the log ft values for the beta decay of ^{134}Te could not be calculated because the Q value was not known. The recent measurements by Lund, Aleklett and Rudstam[24] of 1560 $\pm$ 90 keV has allowed us to determine for the first time the log ft values for beta population to the levels of ^{134}I. These values are shown on Fig.1c. The results of our shell model calculations for the positive parity levels of ^{134}I are given in Tables 2. Elsewhere,[2] we use these configurations as a basis in the accounting of the summed beta strength to the group of 1^+ levels at circa 900 keV in comparison to the unhindered population of the single 1^+ level in ^{132}Sb below 1500 keV..

3.5 Conclusion

When the wavefunctions for ^{132}Sb (Z=51,N=81) are compared to those of its isotone ^{134}I (Z=53,N=81), the main difference in the number of levels with spin-parity values of 1^+ can be attributed to the $(g_{7/2})^3$ cluster configuration. Such a cluster configuration is possible in Z=53 I but impossible in Z=51 Sb. Similarily, neutron hole clusters can account for the additional low energy 1^+ states we observe in ^{130}Sb$_{79}$. Also, we can account for the blocking of beta strength to these levels in the beta decay of ^{130}Sn$_{80}$ in which the cluster configurations are not possible. The interaction of this type of cluster with the quadrupole vibrational field (CVM) has been described by Paar and coworkers[25] and has been tested successfully in a number of odd-mass nuclei where the number of nucleons beyond a single shell closure is three (see for example ref. 26).

REFERENCES

1] R.A. Meyer and E.A. Henry, Ch.2, Spectroscopy of Fission Products, T. von Egidy, Ed., Institute of Physics, Bristol, England,(1980).

2] S.M. Lane, E.A. Henry and R.A. Meyer, UCRL-84492 (sub. to Phys. Rev. 1984).

3] J. Sau and K. Heyde, Phys. Rev. C23 2315 (1981).

4] K. Heyde, J. Sau, E.A. Henry and R.A. Meyer, Phys. Rev. C25 3193 (1982).

5] R.A. Meyer, S.V. Jackson, W.H. Zoller, and W.B. Walters, Phys. Rev. C13 1617 (1976).

6] O.G. Lien III, P.C. Stevenson, R.P. Yaffe, E.A. Henry and R.A. Meyer, Nucl. Instr. & Methods 185 351 (1981).

7] S.M. Lane, Ph.D. Thesis, University of California, Davis, UCRL-52178 (1979).

8] R.F. Hausman, Jr., Ph.D. Thesis, University of California, Davis, UCRL-52178 (1976).

9] S.D. Bloom, J.B. McGrory, and S.A. Moszkowsky, Nucl. Phys. A199 369 (1974).

10] T. Sebe and J. Nachimkin, Ann. of Phys. 51 290 (1972).

11] R.R. Whitehead, Nucl. Phys. A182 290 (1971).

12] R.R. Whitehead, A. Watt, B.J. Cole and I. Morrison, Adv. in Nucl. Phys. 10 123 (1977).

13] J.H. Wilkinson, The Algebraic Eigenvalue Problem, Oxford Univ. Press, London (1965).

14] F. Petrovich, H. McManus, V.A. Madsen and J. Atkinson, Phys. Rev. Lett. 22 895 (1969).

15] A. Kallio and K. Koltveit, Nucl. Phys. 53 87 (1964).

16] C.M. Lederer and V. Shirley, Eds., Table of Isotopes, 7th Ed., J. Wiley Inc., N.Y. (1978).

17] R.A. Meyer and E.A. Henry, NCD-LLNL Ann. Rpt. UCAR 10062-81/1, p116 (1981).

18] A. Kerek, G.B. Holm, P. Carle and J. McDonald, Nucl. Phys.A195 159 (1972).

19] K. Aleklet, E. Lund and G. Rudstam, Nucl. Phys. A281 213 (1977).

20] N.B. Gove and M.J. Martin, Nucl. Data 10 206 (1971).

21] A. Kerek. P. Carle and S. Borg, Nucl. Phys. A224 367 (1974).

22] L.L. Nunnelly and W. Loveland, Phys. Rev. C13 2017 (1976).

23] S. Raman and N.B. Gove, Phys. Rev. C7 1995 (1974).

24] E. Lund, K. Aleklett and G. Rudstam, Nucl. Phys. A286 403 (1977).

25] G.Alaga, V. Paar and L. Sips, "Problems in Vibrational Nuclei", Zagreb, Yugoslavia (1974).

26] H.G. Hicks, J.H. Landrum, E.A. Henry, R.A. Meyer, S. Brant and V. Paar, Phys. Rev. C27 5 (1983).

27] N. Imanishi, I. Fujiwara and T. Nishi, Nucl. Phys. A238 325 (1975).

Table 1. Calculated ${}^{132}_{52}Sb_{81}$ Wavefunctions*

Energy keV	J^{π}	Percent Configurations gd_3^{-1}	gs^{-1}	gh^{-1}	d_5h^{-1}	gd_5^{-1}	d_3h^{-1}	$d_5d_3^{-1}$	d_5s^{-1}
0	4^+	91	9						
61	3^+	80	20						
266	8^-			99	1				
292	5^+	99				1			
334	4^-			99	1				
476	5^-			97	3				
477	7^-			97	2		1		
514	2^+	93				6			
522	4^-			98	1		1		
544	4^+	8	86			6			
570	3^+	19	78			3			
620	3^-			96	4				
937	9^-			100					
1026	3^+							93	6
1142	7^-			1	97		1		
1185	2^+							78	20
1214	6^-				97				
1247	5^-			4	93				
1266	4^-				97		2		
1488	8^-				99				
1539	1^+							98	

*The following orbital notation is used in this and in subsequent table :

$g = 1g_{7/2}$ $d_5 = 2d_{5/2}$ $d_3 = 2d_{3/2}$

$h = 1h_{11/2}$ $s = 3s_{1/2}$

Negative superscripts indicate valence neutron holes; positive indicate valence protons.

Table 2. Calculated $^{134}_{53}I_{81}$ Positive Parity Wavefunctions

Energy keV	Jπ	Percent Configurations							
		g^3d^{-1}	g^3s^{-1}	gd^2d^{-1}	$gd_5^2s^{-1}$	$g^2d_5d_3^{-1}$	$g^3d_5^{-1}$	$d^2d_5s^{-1}$	$d_5^3s^{-1}$
0	4^+	74	5	4					
31	3^+	76	6	5					
98	5^+	81	3	5					
145	2^+	74	9		1				
148	3^+	18	65		5				
277	4^+	15	67	6					
656	3^+					74		9	
770	2^+					56		25	
816	3^+	68	19				1		
941	2^+	42	40				3		
944	1^+	80	12						
993	0^+	93							
1034	3^+					11		61	3
1064	4^+	77	8				1		
1086	6^+	91							
1115	4^+					69		4	2
1162	1^+	4	9			61			
1189	2^+	44	20			7		13	
1202	1^+	47	30	10			4		

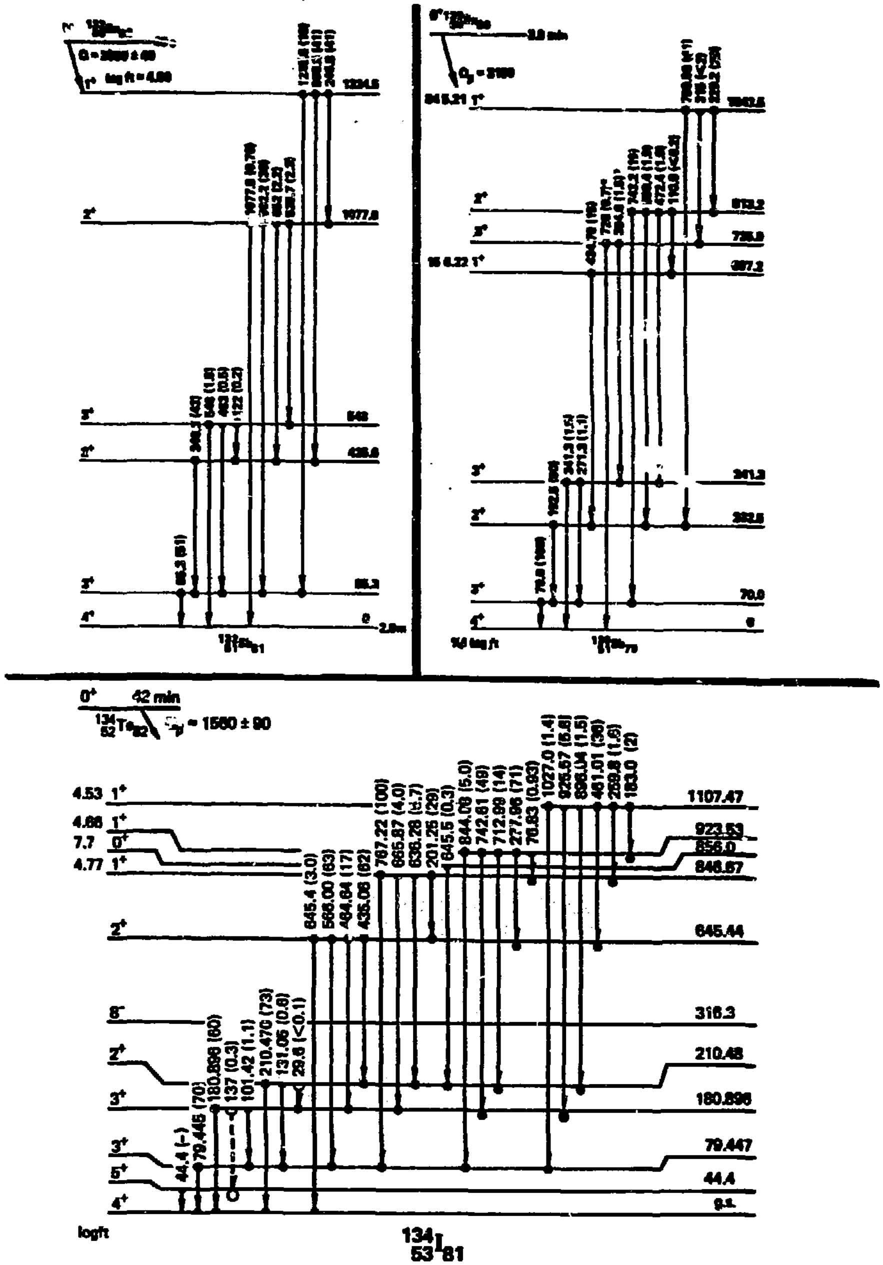

Fig.1. Decay schemes for: a) ^{132}Sn; b) ^{130}Sn; and c) ^{134}Te.